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Age Affects Exercise-Induced Improvements in Heart Rate Response to Exercise

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Key words
- aging
- cardiorespiratory fitness
- exercise
- heart rate
- muscle strength

Abstract

The aim of the present study was to analyze the effects of age on cardiorespiratory fitness (CRF), muscle strength and heart rate (HR) response to exercise adaptation in women in response to a long-term twice-weekly combined aerobic and resistance exercise program. 85 sedentary women, divided into young (YG; n=22, 30.3±6.2 years), early middle-aged (EMG; n=28, 44.1±2.5 years), late middle-aged (LMG; n=20, 56.7±3.5 years) and older (OG; n=15, 71.4±6.9 years) groups, had their CRF, muscle strength (1-repetition maximum test) and HR response to exercise (graded exercise test) measured before and after 12 months of combined exercise training. Exercise training improved CRF and muscle strength in all age groups ($P<0.05$), and no significant differences were observed between groups. Exercise training also improved resting HR and recovery HR in YG and EMG ($P<0.05$), but not in LMG and OG. Maximal HR did not change in any group. Combined aerobic and resistance training at a frequency of 2 days/week improves CRF and muscle strength throughout the lifespan. However, exercise-induced improvements in the HR recovery response to exercise may be impaired in late middle-aged and older women.

Introduction

Poor cardiorespiratory fitness (CRF) [6,34,35] and muscle strength [28,38,40] as well as impaired heart rate (HR) response to exercise (i.e., increased resting, reduced maximal or reserve HR, low recovery HR) [15,27,34,36,39,41] are important risk factors for future chronic disease in men and women. For example, low recovery HR following a graded exercise test (GXT) is an independent risk factor for cardiovascular disease (CVD) and all-cause mortality [15,34,36,39]. Moreover, CVD risk factors have been shown to increase with advancing age, even in the absence of discernible disease [3].

It is well established that physical activity and exercise interventions can improve CRF, muscle strength and HR response to exercise in a variety of population groups [3,9–14]. Evidence also indicates that long-term participation in aerobic and/or resistance based activities can minimize the physiological changes associated with typical aging [3], may lower incidence [3,8,24] and facilitate management of chronic diseases [3,8,9,11,22,23]. Accordingly, regular participation in aerobic and resistance exercise programs for disease prevention, regardless of age or health status, has been recommended by several organizational guidelines [2–4,18,24,37].

Several studies have suggested that age does not affect exercise-induced improvements of CRF and muscle strength [3,10,11]. However, these studies generally analyze the effects of a single intervention (aerobic or resistance exercise) in the short-term (10–16 weeks) and in 2 age groups (young vs. older). Investigations analyzing combined intervention for a longer period over a wide range of age groups are lacking. Moreover, the effects of age on CRF, muscle strength and HR response to exercise adaptation of women in response to a long-term combined aerobic and resistance exercise program are unknown.

Additionally, lack of time is one of most cited barriers for not participating in regular exercise [21]. Although twice-weekly is the minimal resistance exercise frequency recommended in most exercise guidelines and three days-a-week is the minimal exercise frequency recommended for aerobic exercise [2–4,24,37], little is known about the effects of low-frequency (i.e., twice-weekly) combined aerobic and resistance exercise programs.

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Characteristic	YG (n = 30)	EMG (n = 37)	LMG (n = 27)	OG (n = 20)
age, year	30.3 ± 6.2	44.1 ± 2.5	56.7 ± 3.5	71.4 ± 6.9
height, cm	161.8 ± 6.4	160.3 ± 10.7	157.4 ± 6.6[a]	155.4 ± 6.2[b]
weight, kg	58.8 ± 10.4	63.7 ± 10.7	61.4 ± 12.1	63.5 ± 10.8
BMI, kg/m^2	22.4 ± 3.3[c]	24.7 ± 3.6	24.6 ± 3.9	26.3 ± 4.1
waist circumference, cm	80.2 ± 7.8	82.6 ± 15.3	85.0 ± 10.4	92.0 ± 11.0[c]
systolic BP, mmHg	101.9 ± 5.6	109.6 ± 18.6	119.0 ± 17.3[a]	120.6 ± 23.3[a]
diastolic BP, mmHg	65.6 ± 6.4	68.8 ± 10.0	76.0 ± 11.9[b]	72.3 ± 12.8[b]
hypertension, n (%)	–	4 (10.8)	8 (29.6)	8 (40.0)
diabetes, n (%)	–	1 (2.7)	2 (7.4)	3 (15.0)
dyslipidemia, n (%)	–	2 (7.4)	3 (11.1)	4 (20.0)
osteoporosis, n (%)	–	–	–	2 (10.0)
current medication				
CCB, n (%)	–	–	1 (3.7)	1 (5.0)
ACE-I, n (%)	–	1 (2.7)	4 (14.8)	4 (20.0)
diuretics, n (%)	–	4 (10.8)	5 (18.5)	6 (30.0)
metformin, n (%)	–	1 (2.7)	2 (7.4)	3 (15.0)
repaglinide, n (%)	–	–	–	1 (5.0)
statins, n (%)	–	2 (7.4)	3 (11.1)	4 (20.0)
alendronate, n (%)	–	–	–	2 (10.0)

YG, young group; EMG, early middle-aged group; LMG, late middle-aged group; OG, older group; BMI, body mass index; BP, blood pressure; CCB, calcium channel blocker; ACE-I, angiotensin-converting enzyme inhibitor. [a]: different from YG ($P<0.01$). [b]: different from YG and EMG ($P<0.01$). [c]: different from all groups ($P<0.05$)

Table 1 Demographic and clinical characteristics of the study population.

In this context, the aim of the present study was to analyze the effects of a long-term twice-weekly combined aerobic and resistance exercise program on CRF, muscle strength and HR recovery response to exercise in a cohort of adult women of a variety of ages.

Methods

Study design

The study used a 4-group repeated-measures design. All volunteers had their CRF, muscle strength (of all muscle groups trained), and HR response to exercise assessed and compared before and after participation in a 12 month exercise training program. The exercise training program consisted of twice-weekly aerobic and resistance training. This study was approved by the ethics committee for research protocols analysis at our institution and is in accordance with the ethical standards of the International Journal of Sports Medicine [23]. All volunteers read a detailed description of the protocol and provided their written informed consent.

Population

We studied nonsmoking, physically inactive adult women who underwent a pre-participation physical exercise screening between January 1st 2006 and August 31st 2008 before beginning participation in the Cardiovascular and Muscular Fitness Program of the Laboratory of Kinesiology at the Institute of Orthopedics and Traumatology, Medical School, University of Sao Paulo, Brazil. A medical history review and physical evaluation were performed before exercise testing to document any symptoms, history of chronic diseases, current medication, cardiac risk factors and events. All women with musculoskeletal limitation to physical exercise, uncontrolled cardiovascular or metabolic disease, insulin-dependent diabetes, chronic psychological disorders, cardiac disease and/or taking any drug that could potentially influence muscular or cardiovascular response to exercise were excluded from participation in the study. Altogether, 114 women were included in the study (▶ **Table 1**) and were divided into 4 groups according to their age (young group, YG: age < 35 years; early middle-aged group, EMG: age ≥35 and < 50 years; late middle-aged group, LMG: age ≥50 < 65 years; and older group, OG: age ≥65 years). None of the women studied were under hormone replacement therapy, and all premenopausal women had regular menstrual cycles, as confirmed by questionnaire. All women performed a twice-weekly exercise program for 12 months, and underwent a GXT and 1-repetition maximum strength (1-RM) test before and after the 1-year program. Women who did not complete at least 70% of the exercise sessions were excluded from the final analysis.

Graded exercise test (GXT)

Volunteers underwent maximal symptom-limited treadmill (TMX425 Stress Treadmill; TrackMaster, Newton, KS, USA) testing using a Heck modified protocol, carried out between 9:00 a.m. and 12:00 p.m. in a temperature-controlled room (20–23 °C) before commencement of the exercise program and after 12 months of follow-up, and during the follicular phase of their menstrual cycle (days 3 through 9) in menstruating women. All tests consisted of 1 min of rest standing; 1 min each of warm-up at 2.4, 3.6 and 4.8 km/h; increases of 1.2 km/h every 1.5 min until volitional fatigue in the absence of symptoms or other indicators of ischemia [20]; 2 min of recovery at 2.4 km/h; and 1 min of recovery standing. GXT intensity was measured in metabolic equivalents (METs) estimated from treadmill speed and grade using a standardized equation [1]. Exercise tolerance was estimated as the GXT duration. Cardiac rhythm was continuously monitored by 12-lead electrocardiogram (CardioSoft 6.5; GE Medical Systems IT, Milwaukee, WI, USA) and recorded for 10 s at end of rest, end of each warm-up and exercise stage, and at the end of each minute of recovery phase. Recovery HR ($HR_{RECOVERY}$) was considered the difference between the maximal HR (HR_{MAX}) and HR at end of first minute of active recovery (2.4 km/h). Age-predicted HR_{MAX} was estimated by using the equation $208-(0.7\times age)$ [45]. Medications were not changed or stopped before testing. Volunteers were asked to refrain from strenuous physical activities and from consuming beverages containing caffeine or alcohol for 24 h prior to the GXT. Volunteers were also allowed a light meal up to 2 h before testing.

Strength test

To determine muscle strength and the initial workload for each resistance exercise, the 1-RM test was performed after 4 familiarization bouts and 2–5 days after the last exercise training session as previously described [10, 12]. In brief, the 1-RM test was performed using bench press, leg press, seated row, knee extension, shoulder press, knee curl, triceps push-down, calf raise, biceps curl and abdominal exercise using the same weight-lifting machines (Multiflex©, Biodelta Inc., Brazil) and free-weight dumbbells that were used for training. The tests were conducted following the exercise order described above (after proper warm-up), and the 1-RM workload was defined as the maximum weight that could be moved once through the full range of motion with proper form and without performing Valsalva maneuver. All tests were conducted by the same investigator before and after the exercise training period, and the muscle strength data were normalized for body mass with the allometric method (strength [kg] × body mass [kg]$^{-0.67}$) [42]. In our laboratory, the intraclass correlation for 1-RM test-retest measures were 0.983 (95 % confidence interval = 0.964–0.997).

Exercise training program

The exercise sessions were supervised by an exercise specialist, and consisted of twice-weekly aerobic and resistance exercise program. Aerobic exercise was performed at the beginning of each exercise session (after a 5-min warm-up) and consisted of 20 min of cycle-ergometer or treadmill walking, rotating between both every 2 sessions at 60–80 % of reserve HR (monitored by a heart rate monitor [Polar©, Kempele, Finland]) [29]. Resistance exercise consisted of 2–3 sets (2 sets during the first 3 months and 3 sets during the remaining months) of 8–12 repetitions at 60–80 % of 1-RM, performed in all the exercises described in 1-RM test, totalizing ~25 min (first 3 months) to ~40 min (remaining months) of resistance training. To promote sufficient workload for eliciting improvements throughout the 12 months of training, the exercise intensity of the aerobic and resistance exercises was increased by 5–10 %, whenever adaptation occurred. Aerobic exercise adaptation was considered an exercise HR between 60–70 % of the subjects' reserve HR and scale of perceived effort of 11–13 [7] for 2 consecutive exercise sessions. Resistance exercise adaptation was considered to be achieved when 12 repetitions with proper form were performed in all sets of a given exercise for 2 consecutive exercise sessions. If subjects were unable to sustain HR between 70–80 % or perform at least 8 repetitions (with proper form) after exercise intensity increased, aerobic or resistance exercise returned to previous intensity for an additional 2 exercise sessions. All groups performed morning exercise sessions.

Statistical methods

Data are reported as means ± standard deviation, except for resting and recovery HR changes after training which are reported as median and 95 % confidence interval (CI). SigmaStat 3.5 for Windows (Systat Software Inc., Chicago, IL, USA) was used to perform the statistical analysis. The Kolmogorov–Smirnov test was applied to ensure a Gaussian distribution of the data. One-way analysis of variance (ANOVA) and Kruskal-Wallis test were used to indicate differences between groups in parametric and nonparametric data of subjects' characteristics, respectively. Two-way ANOVA with repeated measurements (group vs. time) was used to indicate inter- and intra-group differences in the GXT and 1-RM test data. One-way ANOVA was also used to indicate differences between groups in the post-training changes of GXT and 1-RM test data. The Bonferroni post-hoc analysis was used to identify significant differences that were indicated by both one-way and two-way ANOVA, and the post-hoc Dunn's test was used to determine significant data indicated by Kruskal-Wallis. Statistical significance was set at $P < 0.05$.

Results

During the experimental period, 29 volunteers were unable to complete the study: 17 were unable to complete the exercise program for personal reasons (YG = 5, EMG = 5, LMG = 4 and OG = 3) and 12 did not have the minimal exercise training compliance of 70 % (YG = 3, EMG = 4, LMG = 3 and OG = 2). There were no significant differences in the baseline characteristics between the subjects that completed and did not complete the study (data not shown). No significant differences between groups were observed in exercise training compliance (YG = 87.5 ± 7.7 %; EMG = 86.2 ± 8.9 %; LMG = 90.5 ± 7.1 %; OG = 88.1 ± 6.5 %). Neither BMI nor waist circumference were different after 12 months of follow-up in the YG (BMI=22.3±1.9 vs. 22.6±1.6 kg/m^2; waist circumference=79.7±7.6 vs. 78.6±5.6 cm), EMG (BMI=25.8±3.7 vs. 24.5±2.8 kg/m^2; waist circumference=84.4±8.2 vs. 84.2±6.1 cm), LMG (BMI=24.7±4.1 vs. 23.0±2.2 kg/m^2; waist circumference=83.3±10.5 vs. 82.4±6.9 cm) or OG (BMI=26.5±4.3 vs. 26.3±3.8 kg/m^2; waist circumference=91.2±11.1 vs. 91.1±11.7 cm).

GXT parameters are displayed in **Table 2**. All tests were stopped because of volitional fatigue (rate of perceived exertion of 19 or 20) and all subjects attained at least 92 % of their age predicted HR_{MAX} (range of 92–116 %). Pre- and post-training exercise capacity, exercise tolerance and HR_{MAX} were lower in OG than in YG, EMG, LMG, and lower in EMG and LMG than in YG. EMG and LMG did not show significant differences in pre- and post-training exercise capacity and exercise tolerance. However, HR_{MAX} was lower in LMG than in EMG. Baseline $HR_{RESTING}$, $HR_{RECOVERY}$ and percentage of the predicted HR_{MAX} did not differ among the 4 age groups.

The twice-weekly exercise program was effective for improving CRF in all groups ($P < 0.05$). During follow-up, the mean exercise capacity and exercise tolerance improvement varied from 8.4 ± 1.8 % (YG) to 12.1 ± 1.3 % (OG) and 11.6 ± 3.5 % (YG) to 17.3 ± 3.4 % (OG), respectively. There were no significant differences between groups in the percentage of CRF improvement (**Fig. 1**).

On the other hand, the exercise training adaptation of HR response to exercise was different between groups. YG and EMG showed reductions in $HR_{RESTING}$ and increases in $HR_{RECOVERY}$ during follow-up ($P < 0.05$). No significant changes were observed in $HR_{RESTING}$ and $HR_{RECOVERY}$ of EMG and OG (**Fig. 2**). With these results, LMG and OG displayed lower post-training $HR_{RECOVERY}$ than YG and EMG. HR_{MAX} and percentage of the predicted HR_{MAX} did not change in any group during follow-up (**Table 2**). No association was found between $HR_{RECOVERY}$ and exercise capacity, exercise tolerance, BMI or waist circumference for any group (**Table 4–9**).

Baseline muscle strength was lower in OG than in YG, EMG and LMG, and lower in EMG and LMG than in YG in all exercises tested ($P < 0.01$, **Table 3**). Although LMG showed lower baseline muscle strength levels than EMG, this difference was significant only in the knee curl exercise ($P < 0.01$). As noted in **Table 3**, the twice-weekly exercise program was effective for improving muscle strength in all groups. After the interven-

Table 2 Cardiorespiratory fitness and heart rate response to exercise before and after combined aerobic and resistance exercise training.

Variable	YG (n = 22)	EMG (n = 28)	LMG (n = 20)	OG (n = 15)
exercise capacity, METs				
before	10.7 ± 1.3	9.4 ± 1.3[a]	8.9 ± 1.4[a]	8.1 ± 1.7[c]
after	11.6 ± 1.4[d]	10.2 ± 0.7[a,d]	9.9 ± 1.1[a,d]	9.1 ± 1.3[c,d]
exercise tolerance, min				
before	11.2 ± 1.5	9.2 ± 1.4[a]	8.7 ± 1.3[a]	7.2 ± 1.6[c]
after	12.5 ± 1.7[d]	10.3 ± 0.8[a,d]	9.9 ± 1.2[a,d]	8.4 ± 1.4[c,d]
$HR_{RESTING}$, bpm				
before	84.2 ± 8.8	86.2 ± 8.9	82.7 ± 11.1	81.8 ± 10.1
after	79.7 ± 8.6[d]	78.4 ± 8.5[d]	81.0 ± 8.8	80.7 ± 9.1
HR_{MAX}, bpm				
before	192.3 ± 6.3	183.7 ± 9.3[a]	175.9 ± 9.5[b]	163.0 ± 13.9[c]
after	191.9 ± 4.2	179.8 ± 9.0[a]	174.8 ± 9.2[b]	165.7 ± 15.3[c]
% of predicted HR_{MAX}, %				
before	103.1 ± 4.1	103.8 ± 5.1	103.3 ± 6.0	100.2 ± 7.5
after	102.7 ± 2.8	101.2 ± 6.5	102.8 ± 5.3	101.9 ± 8.9
$HR_{RECOVERY}$, bpm				
before	22.4 ± 9.7	22.7 ± 11.3	17.3 ± 8.2	18.8 ± 10.9
after	32.0 ± 9.0[d]	29.1 ± 9.6[d]	19.1 ± 9.6[b]	19.4 ± 11.1[b]

YG, young group; EMG, early middle-aged group; LMG, late middle-aged group; OG, older group; bpm, beats per minute; HR, heart rate; MAX, maximal. [a]: different from YG (P < 0.01). [b]: different from YG and EMG (P < 0.01). [c]: different from all groups (P < 0.05). [d]: different from before exercise training (P < 0.05)

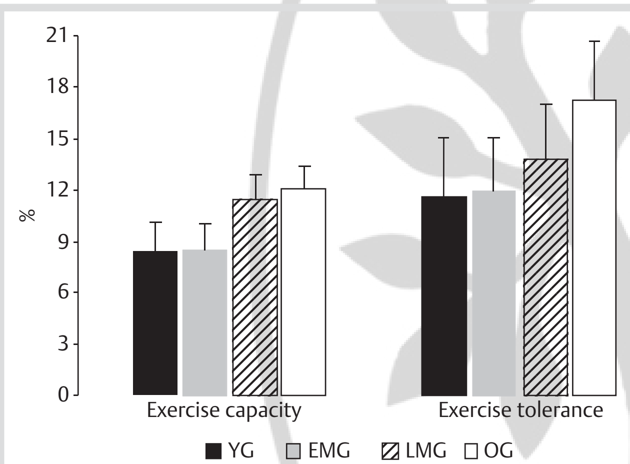

Fig. 1 Exercise capacity (left panel) and exercise tolerance (right panel) improvement as a percentage after 12 months of combined aerobic and resistance exercise training. YG, young group (n = 22); EMG, early middle-aged group (n = 28); LMG, late middle-aged group (n = 20); OG, older group (n = 15).

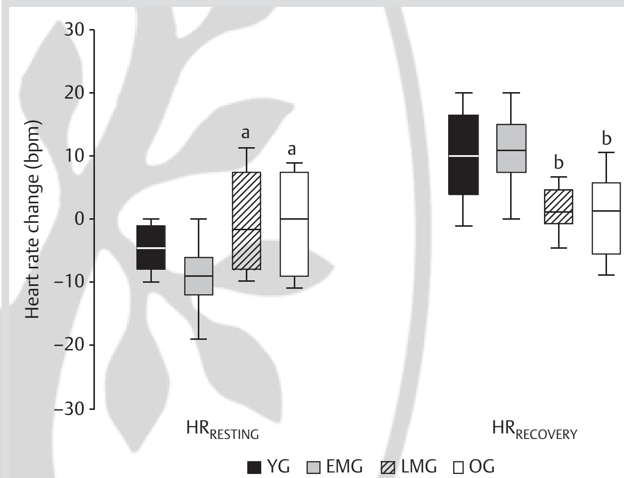

Fig. 2 Resting (left panel) and recovery (right panel) heart rate changes after 12 months of combined aerobic and resistance exercise training. YG, young group (n = 22); EMG, early middle-aged group (n = 28); LMG, late middle-aged group (n = 20); OG, older group (n = 15). [a]: different from EMG (P < 0.05). [b]: different from YG and EMG (P < 0.05).

tion, strength improved in all groups for all exercises, and the mean muscle strength improvement varied from 26.5 ± 10.6 % (biceps curl of LMG) to 66.5 ± 19.3 % (bench press of OG). Additionally, there were no significant differences among groups in terms of the percentage of muscle strength improvement in all exercises (▶ **Fig. 3**).

Discussion

The primary finding of the present study was that a 1-year, twice-weekly combined aerobic and resistance exercise training program was effective for improving muscle strength and CRF in adult women, regardless of age. However, this combined training program was effective in improving HR recovery response to exercise in young and early middle-aged, but not in late middle-aged and older women. To the best of our knowledge, this is the first prospective study that compared the effects of a long-term combined resistance and aerobic exercise training on CRF, muscle strength and HR recovery response to exercise among adult women of different age groups.

The age-related decline of CRF and muscle strength, and the role of aerobic and resistance training in reversing or reducing this decline is well documented [3]. Moreover, the relative increases in CRF and muscle strength after an exercise training program has been generally similar between young and older men and women [3, 10, 12, 43]. Although negative findings exist [32, 33], previous studies using 2 age groups (young vs. older) for analyzing the effects of age on muscle strength response to a short-term resistance training have noted similar strength increases (17–49 %) between young and older men and women after 10–16 weeks of 2–3 day/week programs [10, 12, 30, 31]. The

1-RM test, kg·kg$^{-0.67}$	YG (n = 22)	EMG (n = 28)	LMG (n = 20)	OG (n = 15)
bench press				
before	1.38 ± 0.21	1.08 ± 0.14^{a}	1.02 ± 0.14^{a}	0.78 ± 0.11^{c}
after	2.11 ± 0.36^{d}	1.56 ± 0.21^{a,d}	1.51 ± 0.19^{a,d}	1.29 ± 0.24^{c,d}
leg press				
before	6.31 ± 0.64	5.05 ± 0.77^{a}	4.64 ± 0.71^{a}	4.10 ± 0.67^{c}
after	8.83 ± 1.13^{d}	6.94 ± 1.01^{a,d}	6.62 ± 0.94^{a,d}	6.21 ± 0.86^{b,d}
seated row				
before	2.54 ± 0.25	2.14 ± 0.22^{a}	2.08 ± 0.23^{a}	1.79 ± 0.19^{c}
after	3.41 ± 0.42^{d}	3.01 ± 0.36^{a,d}	2.82 ± 0.22^{a,d}	2.57 ± 0.38^{b,d}
knee extension				
before	1.69 ± 0.37	1.39 ± 0.22^{a}	1.27 ± 0.21^{a}	0.98 ± 0.19^{c}
after	2.56 ± 0.43^{d}	2.14 ± 0.34^{a,d}	1.87 ± 0.23^{a,d}	1.38 ± 0.20^{c,d}
shoulder press				
before	1.07 ± 0.18	0.79 ± 0.12^{a}	0.70 ± 0.12^{a}	0.52 ± 0.13^{c}
after	1.71 ± 0.32^{d}	1.17 ± 0.19^{a,d}	1.08 ± 0.17^{a,d}	0.85 ± 0.12^{c,d}
knee curl				
before	2.19 ± 0.22	1.84 ± 0.19^{a}	1.51 ± 0.18^{b}	1.18 ± 0.15^{c}
after	3.47 ± 0.53^{d}	2.77 ± 0.43^{a,d}	2.34 ± 0.34^{b,d}	1.93 ± 0.33^{c,d}
triceps push-down				
before	1.47 ± 0.12	1.26 ± 0.17^{a}	1.14 ± 0.15^{a}	0.94 ± 0.12^{c}
after	2.30 ± 0.31^{d}	1.81 ± 0.29^{a,d}	1.72 ± 0.19^{a,d}	1.49 ± 0.22^{c,d}
calf raise				
before	7.38 ± 0.85	6.29 ± 0.76^{a}	6.01 ± 0.71^{a}	4.93 ± 0.63^{c}
after	10.86 ± 1.15^{d}	9.79 ± 1.06^{d}	9.53 ± 0.94^{a,d}	7.93 ± 0.93^{c,d}
biceps curl				
before	0.97 ± 0.11	0.91 ± 0.09	0.89 ± 0.09^{a}	0.74 ± 0.08^{c}
after	1.27 ± 0.14^{d}	1.19 ± 0.14^{d}	1.13 ± 0.09^{a,d}	0.99 ± 0.13^{c,d}
abdominal				
before	3.76 ± 0.67	3.23 ± 0.59	3.14 ± 0.47^{a}	2.73 ± 0.41^{c}
after	5.63 ± 0.94^{d}	4.94 ± 0.91^{d}	4.73 ± 0.58^{a,d}	4.16 ± 0.53^{c,d}

YG, young group; EMG, early middle-aged group; LMG, late middle-aged group; OG, older group; 1-RM, 1-repetiton maximum. ^{a}: different from YG (P < 0.01). ^{b}: different from YG and EMG (P < 0.01). ^{c}: different from all groups (P < 0.05). ^{d}: different from before exercise training (P < 0.001)

Table 3 Muscle strength before and after combined aerobic and resistance exercise training.

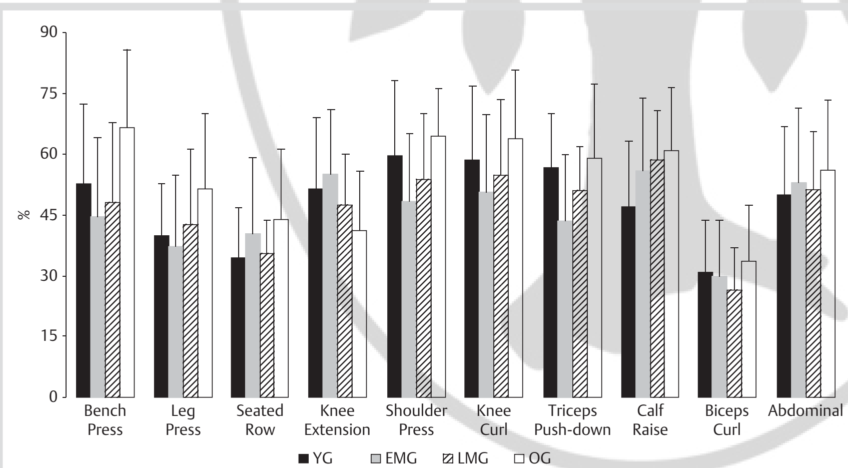

Fig. 3 Upper- and lower-extremity muscle strength (1-RM test) increase after 12 month of exercise training. YG: young control group. EMG: early middle-aged group. LMG: late middle-aged group. OG: older group.

present study added 2 groups of middle-aged women (early and late middle-aged) with the aim of analyzing training adaptation across the adult age span, and found no significant difference in muscle strength increases among the 4 age groups analyzed after long-term training, which confirms the preserved strength adaptation to resistance training with advancing age in adult women. Additionally, similar muscle strength increases between young and older women also occurred.

Although few studies have applied the same aerobic exercise training in young and older women, relative CRF increases after exercise training would also appear to not be affected by age [3]. Well controlled studies lasting 16–20 weeks, applying exercise interventions of intensity equal to or greater than 60% of maximal aerobic capacity (or reserve HR) and involving a training frequency of at least 3 days/week have reported increases in the maximal aerobic capacity of older subjects that are similar to those observed in young women [25,43]. When young and older subjects performed the same aerobic exercise program, similar relative increases of maximal aerobic capacity were observed in both groups during 6 months of follow-up (21% in older and 17% in young subjects) [44]. In the present

Table 4 Relative recovery intensity (% of maximal exercise speed) before and after combined aerobic and resistance exercise training.

Variable	YG (n=22)	EMG (n=28)	LMG (n=20)	OG (n=15)
relative recovery intensity, %				
before	21.1±2.2	24.9±2.7[a]	25.8±3.5[a]	30.6±5.3[b]
after	19.1±1.7[c]	23.4±1.4[a,c]	22.4±3.0[a,c]	27.8±4.6[b,c]

YG, young group; EMG, early middle-aged group; LMG, late middle-aged group; OG, older group. [a]: different from YG ($P<0.01$). [b]: different from all groups ($P<0.05$). [c]: different from before exercise training ($P<0.05$)

Table 5 Pearson's coefficient of correlation between $HR_{RECOVERY}$ and relative recovery intensity before and after combined aerobic and resistance exercise training.

Variable	YG (n=22)	EMG (n=28)	LMG (n=20)	OG (n=15)
R				
before	0.19	0.25	0.24	−0.13
after	−0.11	−0.33	−0.23	0.06

YG, young group; EMG, early middle-aged group; LMG, late middle-aged group; OG, older group. P=N/S

Pearson's coefficient of correlation between $HR_{RECOVERY}$ and relative recovery intensity for the combined group was 0.11

Table 6 Pearson's coefficient of correlation between $HR_{RECOVERY}$ and BMI before and after combined aerobic and resistance exercise training.

Variable	YG (n=22)	EMG (n=28)	LMG (n=20)	OG (n=15)
R				
before	−0.19	0.26	−0.08	0.26
after	−0.06	0.19	0.11	0.25

YG, young group; EMG, early middle-aged group; LMG, late middle-aged group; OG, older group. P=N/S

Pearson's coefficient of correlation between $HR_{RECOVERY}$ and BMI for the combined group was 0.11

Table 7 Pearson's coefficient of correlation between $HR_{RECOVERY}$ and waist circumference before and after combined aerobic and resistance exercise training.

Variable	YG (n=22)	EMG (n=28)	LMG (n=20)	OG (n=15)
R				
before	0.24	0.31	0.05	0.08
after	−0.01	−0.21	0.06	0.13

YG, young group; EMG, early middle-aged group; LMG, late middle-aged group; OG, older group. P=N/S

Pearson's coefficient of correlation between $HR_{RECOVERY}$ and waist circumference for the combined group was 0.09

Table 8 Pearson's coefficient of correlation between $HR_{RECOVERY}$ and exercise capacity (METs) before and after combined aerobic and resistance exercise training.

Variable	YG (n=22)	EMG (n=28)	LMG (n=20)	OG (n=15)
R				
before	−0.28	−0.23	−0.06	0.15
after	0.28	0.25	0.21	0.07

YG, young group; EMG, early middle-aged group; LMG, late middle-aged group; OG, older group. P=N/S

Pearson's coefficient of correlation between $HR_{RECOVERY}$ and exercise capacity (METs) for the combined group was 0.03

Table 9 Pearson's coefficient of correlation between $HR_{RECOVERY}$ and exercise tolerance (min) before and after combined aerobic and resistance exercise training.

Variable	YG (n=22)	EMG (n=28)	LMG (n=20)	OG (n=15)
R				
before	−0.10	−0.26	−0.15	0.11
after	0.21	0.35	0.11	−0.05

YG, young group; EMG, early middle-aged group; LMG, late middle-aged group; OG, older group. P=N/S

Pearson's coefficient of correlation between $HR_{RECOVERY}$ and exercise tolerance (min) for the combined group was 0.04

study, the improvements in exercise capacity and exercise tolerance were not significantly different between young, middle-aged (early and late) and older women, confirming the preserved CRF adaptation to exercise. It is important to emphasize that, although 3 days/week is generally considered the minimal exercise frequency recommended for improving CRF [3], the twice-weekly exercise program used in the present study was sufficient for significantly increasing the CRF of adult women regardless of age.

The evaluation of HR response to GXT has been established as an easy and inexpensive tool that provides a wealth of information on the interaction of the autonomic nervous system and cardiovascular system at various phases of rest, exercise and recovery [26,27,41]. Although it is well described that there is a reduction in HR_{MAX} with advancing age, little is known about the effects of age on $HR_{RECOVERY}$, a marker that is an independent risk factor for CVD and all-cause mortality [15,34,36,39]. A previous study comparing the HR response to exercise between males below and above the age of 40 found a reduced $HR_{RECOVERY}$ in older compared to younger men [17]. On the other hand, the present study did not find any difference in the baseline $HR_{RECOVERY}$ between young, middle-aged (early and late) and older women. Differences in the population studied, exercise protocol used and method to measure HR may explain the discrepancies between the present and previous study. Moreover, the previous study included individuals who were physically active recreationally, but did not quantify the degree of their activity. Accordingly, a study analyzing the effects of age on HR response to exercise found no significant differences on $HR_{RECOVERY}$ when comparing young vs. older sedentary or young vs. older trained men [16]. However, trained men showed faster $HR_{RECOVERY}$ than sedentary men, irrespective of age [16].

Despite the lack of age effects on baseline $HR_{RECOVERY}$, our findings suggest that age may affect exercise-induced improvements in $HR_{RECOVERY}$. In both the YG and EMG groups, an increased $HR_{RECOVERY}$ response was noted after the training program, while no significant improvement was observed in LMG and OG. In contrast, an improvement of ~5 bpm was observed in $HR_{RECOVERY}$ of older subjects that performed 30 min of aerobic exercise 3 times per week for 8 weeks [19]. A previous study from our group also noted an $HR_{RECOVERY}$ improvement of ~6 bpm in postmenopausal women of normal weight after 12 months of a thrice-weekly aerobic and resistance training program [13]. Because the positive effect of exercise training on $HR_{RECOVERY}$ of older subjects was noted after aerobic exercise programs with greater volume (30 min) and/or frequency (3 times per week), it is reasonable to speculate that the 20 min twice-weekly aerobic exercise program performed in the present study was not sufficient for improving $HR_{RECOVERY}$ in late middle-aged and older women. However, it is important to emphasize that the previous studies showing

$HR_{RECOVERY}$ improvement after aerobic exercise of longer volume and greater frequency did not have a young group for comparison. Although the precise mechanism is not completely understood, the initial HR decrease following exercise is thought to be mediated primarily by vagal reactivation [13–15, 26, 36], and is independent of sympathetic withdrawal and exercise workload [26]. Moreover, it appears that this vagal reactivation is regulated by central mechanism(s) (e.g., cessation of central command from the cerebral motor cortex) rather than peripheral factor(s) (e.g., changes in the stimuli to metaboreceptors and baroreceptors) [26]. In this context, the improved postexercise $HR_{RECOVERY}$ observed only in YG and EMG suggests a greater exercise-induced improvement of parasympathetic response of YG and EMG than LMG and OG. It is important to note that there are other metabolic and hemodynamic factors that were not assessed and may influence $HR_{RECOVERY}$ (e.g. resting BP, arterial stiffness, total and LDL cholesterol) [5]. However, the relationship between these factors and $HR_{RECOVERY}$ are generally weak and occurs with longer recovery periods (2 min), whereas the only independent factor associated with 1-min $HR_{RECOVERY}$ in women was LDL cholesterol [5]. Although the possible influence of the aforementioned mentioned factors on 1-min $HR_{RECOVERY}$ is low, future investigations should seek to indentify the influence of these and other risk factors on exercise-induced improvements in $HR_{RECOVERY}$ of different age groups, as some of these factors (e.g. arterial stiffness) may affect adaptation to exercise depending on participants' age [22].

The postexercise reduction of $HR_{RESTING}$ observed in YG and EMG, but not in LMG and OG, also suggests an age effect on exercise-induced improvement of autonomic nervous system function at rest. However, unlike the HR response to exercise, $HR_{RESTING}$ may be influenced by numerous extraneous factors. Even when HR was measured during the sleeping hours, the intra-subject day-to-day variation of the minimum HR during sleep was about 5 bpm [46]. Accordingly, different populations have shown exercise-induced changes in $HR_{RESTING}$ that vary from no significant differences to a 10 bpm reduction [11, 13, 14].

A limitation of the present study is the absence of a sedentary control group. Although we did not directly measure oxygen consumption, the exercise-induced improvement in exercise capacity (METs) and exercise tolerance are correlates of CRF [20]. The constant treadmill speed (2.4 km/h) during recovery phase of GXT does not represent the same relative intensity (percentage of maximal speed) for women of different CRF, which may influence $HR_{RECOVERY}$ (▶ **Table 4**). However, we did not find any significant correlation between $HR_{RECOVERY}$ and relative recovery intensity (▶ **Table 5**), suggesting that the difference between groups in relative recovery probably did not affect $HR_{RECOVERY}$ in present study. Future studies with stationary recovery or recovery fixed in the same relative intensity for all age groups are needed to confirm the present findings. Although the number of women taking medication was relatively low (▶ **Table 1**), the medication intake was different between young and older groups. Since the effects of these specific medications on variables studied are unknown, future investigations analyzing their effects on the variables analyzed would be welcome. Additionally, the inclusion of only women without orthopedic or cardiovascular limitations to exercise makes it difficult to extrapolate the present findings to other populations, mainly the elderly population with physical limitations or poorly managed chronic disorders.

In summary, the twice-weekly exercise program promoted similar improvements in the muscle strength and CRF of adult women of different age groups. However, only young and early middle-aged women exhibited improved HR response to exercise following exercise training. These results suggest that exercise-induced improvements in HR response to exercise may be impaired in late middle-aged and older women. Furthermore, the clinical impact of improvements in CRF and strength independent of changes in $HR_{RECOVERY}$ in the older age groups is unclear.

Clinical Implication

Several studies have noted that the simple application of HR provides powerful risk stratification for CVD and mortality from the exercise test in different populations [15, 27, 34, 36, 41]. Accordingly, reduced $HR_{RECOVERY}$ to exercise is an independent risk factor for CVD and all cause mortality in women, regardless of age [15, 34, 39]. Low CRF and muscle strength are also strong predictors of physical disability, cardiovascular and metabolic disease and mortality [3, 28, 34, 35, 38, 40]. In this context, the exercise-induced increase of CRF and muscle strength observed in all groups suggests that a twice-weekly combined aerobic and resistance exercise program may have important implications for disease prevention and management in adult women of different ages, and may be an alternative for adult women who are unable to perform thrice-weekly aerobic exercise [2–4, 25, 37], regardless of age.

In contrast, the lack of $HR_{RECOVERY}$ improvement after the twice-weekly exercise program in LMG and OG, associated to the improvements observed in older subjects who performed aerobic exercise programs with greater volume (30 min) and frequency (3 times per week) [13, 19], may have important implications for the design of exercise programs for late middle-aged and older women. However, multicenter prospective studies with long-term follow-up focused on comparing the influence of different exercise training frequencies (e.g. 2 vs. 3 times-a-week) on disease prevention and management in women of different ages are necessary for confirming our hypothesis.

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